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(54) THIN FILM COIL AND METHOD OF FORMING THE SAME, THIN FILM MAGNETIC HEAD, THIN FILM INDUCTOR AND THIN FILM MAGNETIC SENSOR

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(52) **U.S. Cl.** **360/123**

(57) **ABSTRACT**

The present invention provides a thin film coil with low resistance and low inductance, and a method of forming the thin film coil, and a thin film magnetic head, a thin film inductor and a thin film magnetic sensor each using the thin film coil. In the thin film coil, at least the side surfaces of the conductor of a first coil are completely coated with an insulating film, and the conductor of a second coil is formed on a substrate with the insulating film provided therebetween. The thin film coil is formed by forming a plating underlying film on the substrate, forming the conductor of the first coil, etching off the plating underlying film except the portion below the conductor, forming the insulating film over the entire surface, forming a second plating underlying film on the insulating film, forming the conductor of the second coil by plating on the portion of the second plating film **16,** which corresponds to the pitch interval of the first coil, and removing the second plating underlying film on the insulating film of the first coil.

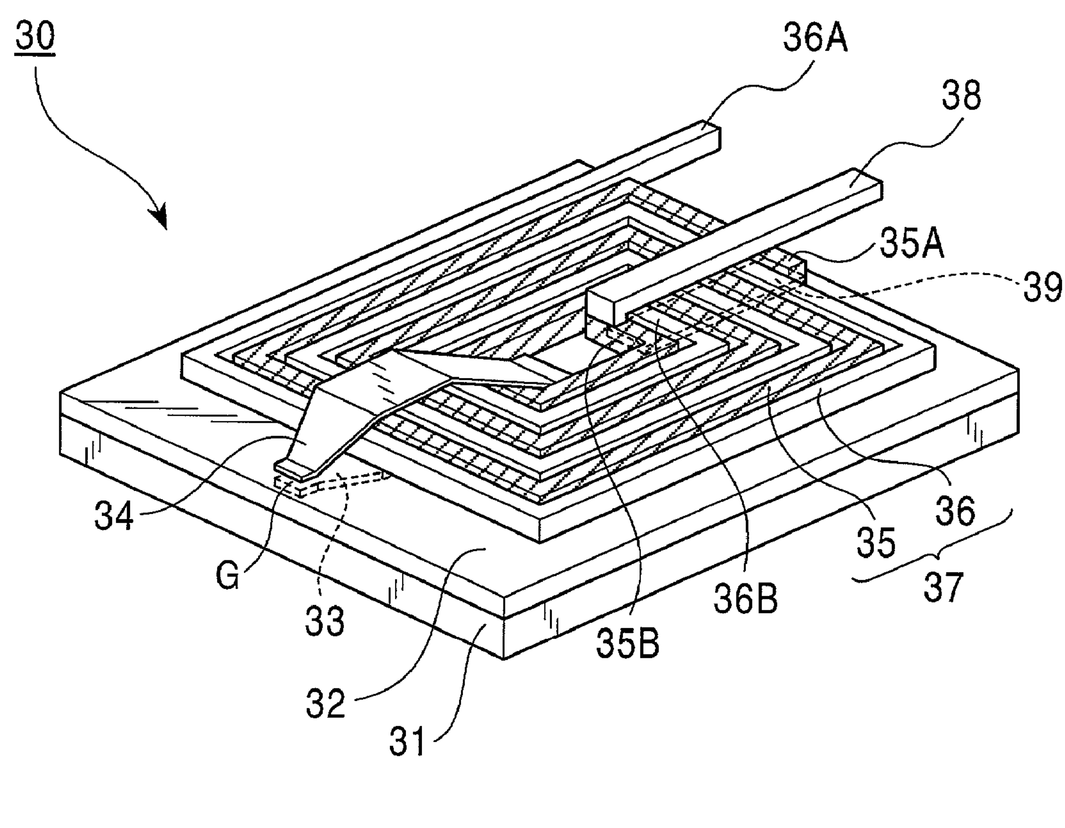


FIG. 1

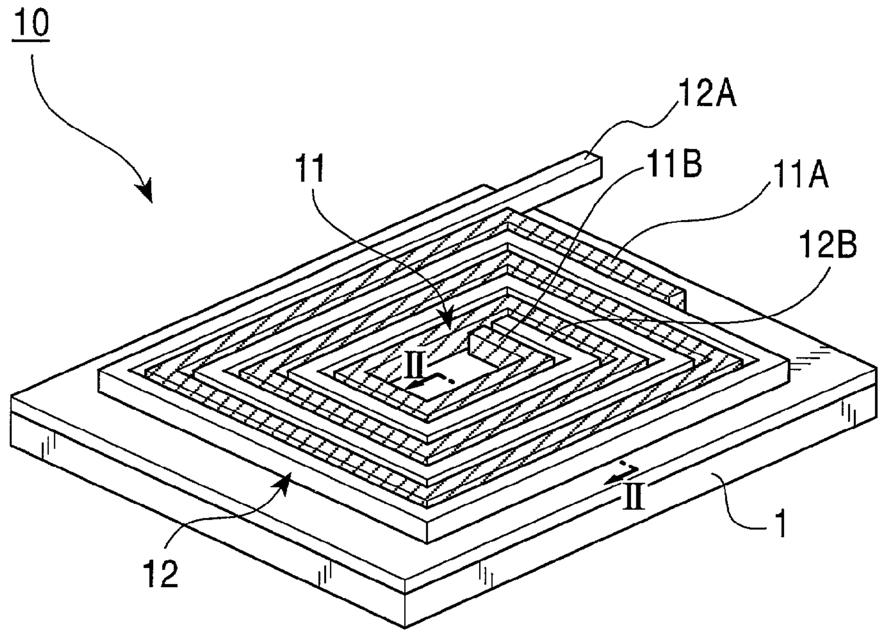
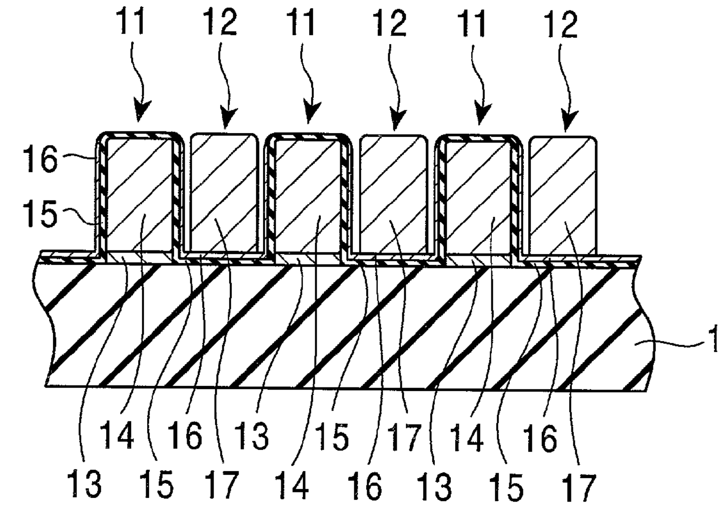

10
12A
11
11B
11A
12B
II
II
1
12

FIG. 2


11
12
11
12
11
12
16
15
1
13
14
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15
16
17

FIG. 3A

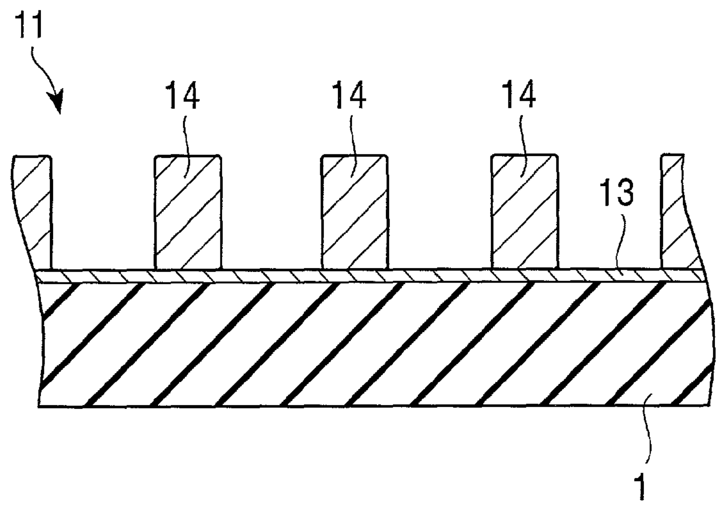


FIG. 3B

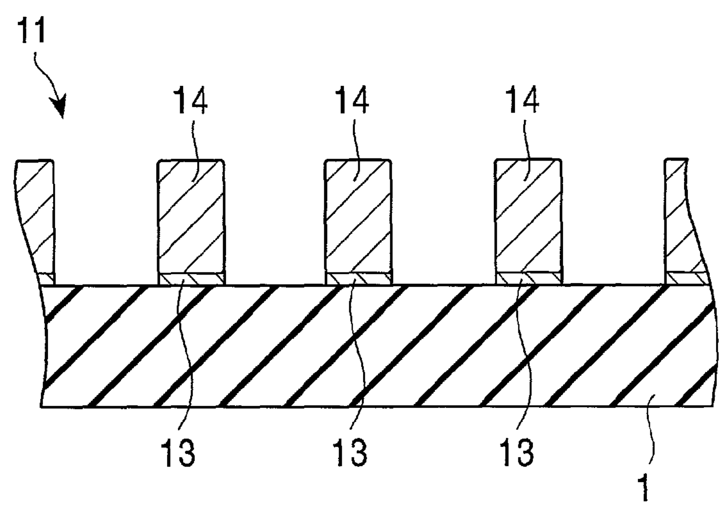


FIG. 3C

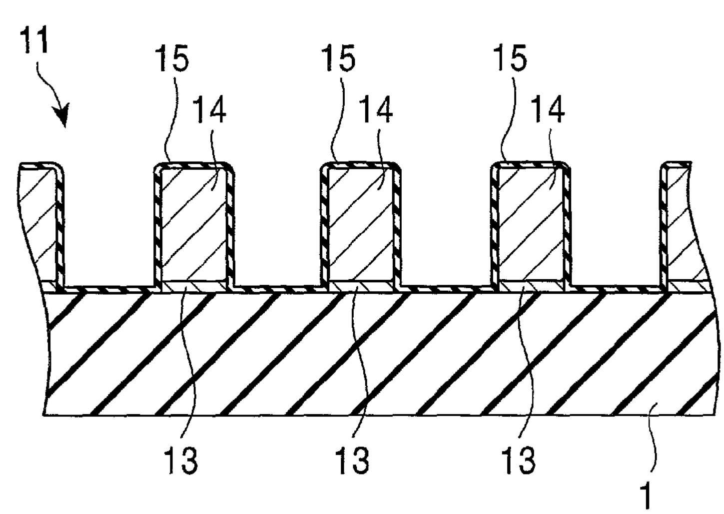


FIG. 4D

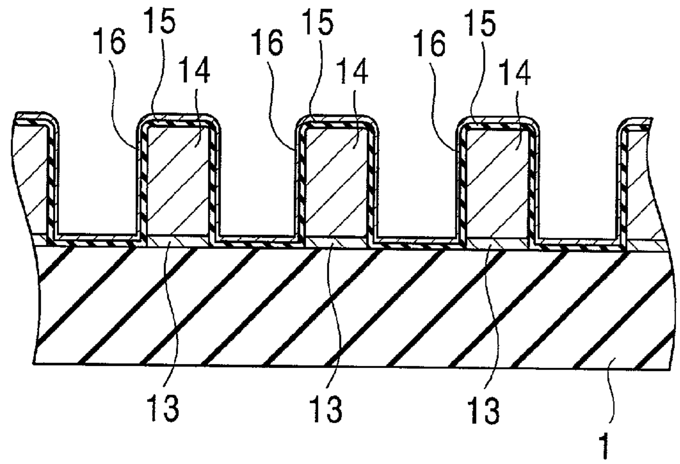


FIG. 4E

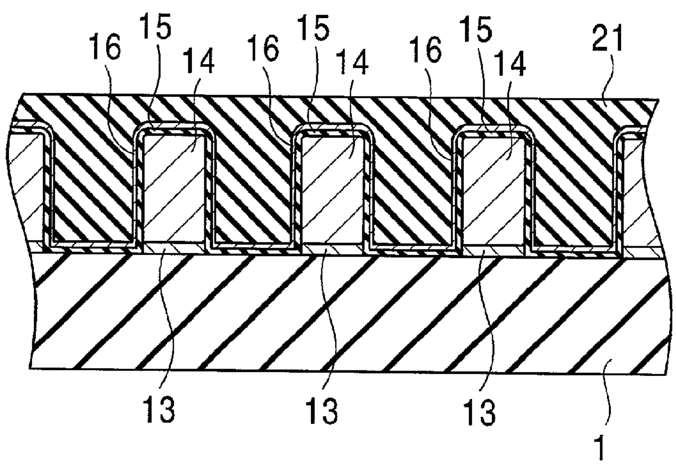


FIG. 4F

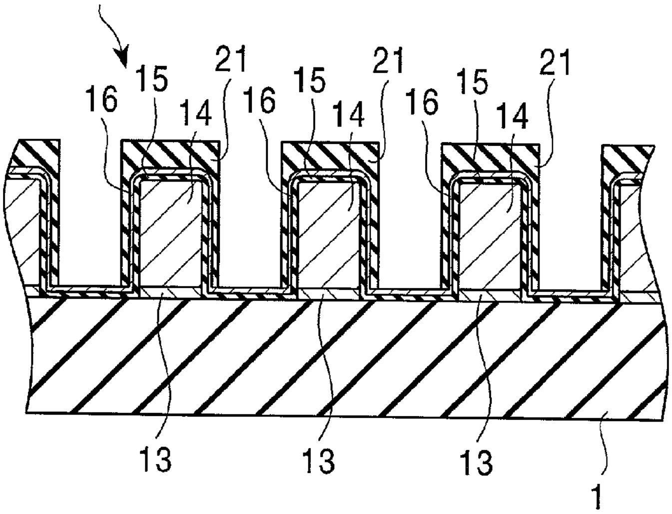


FIG. 5G

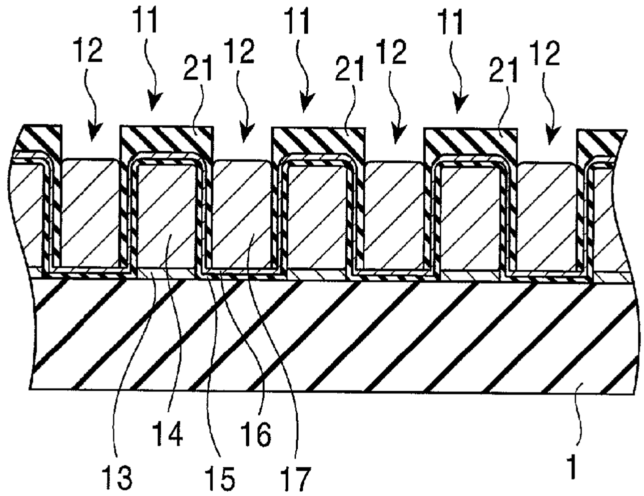


FIG. 5H

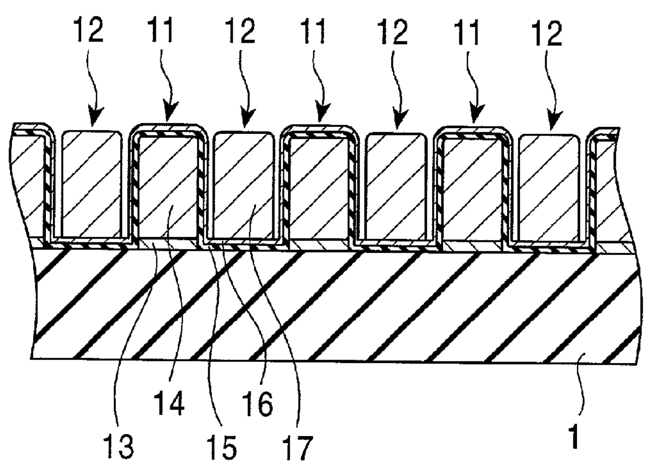


FIG. 5I

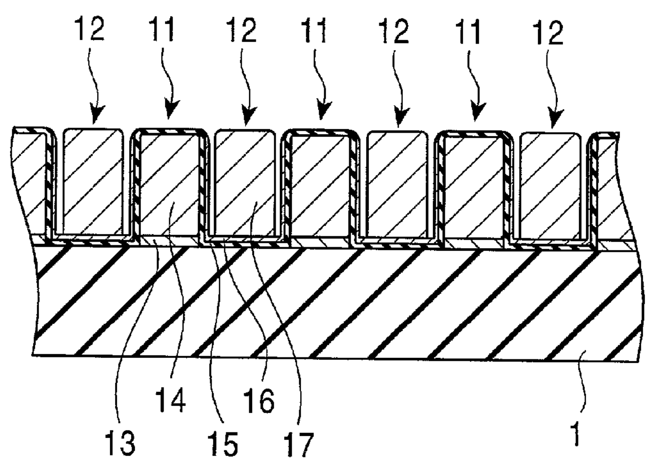


FIG. 6

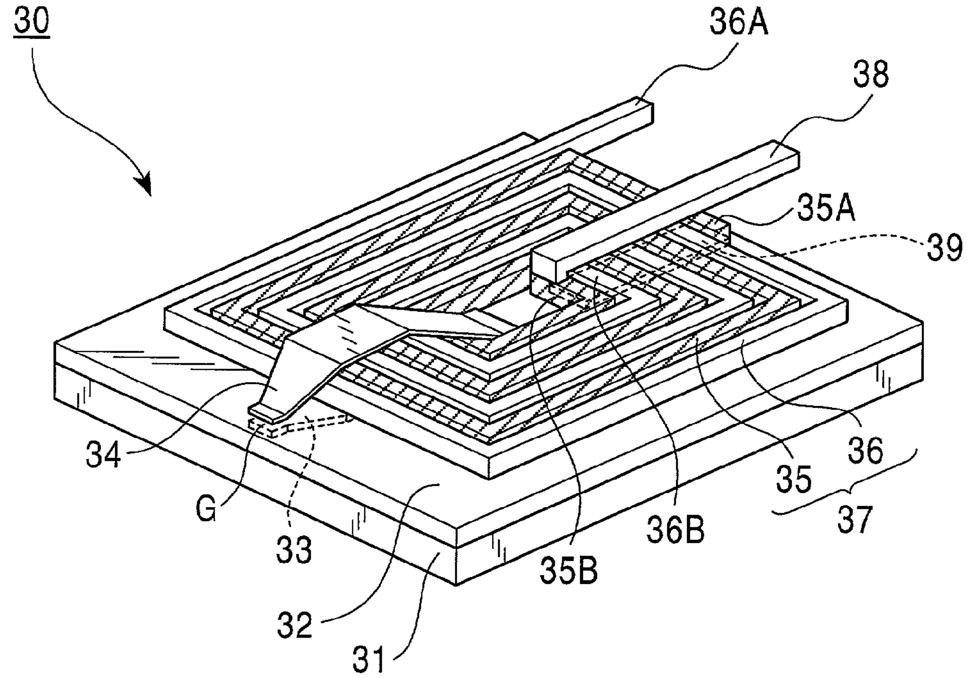


FIG. 7A

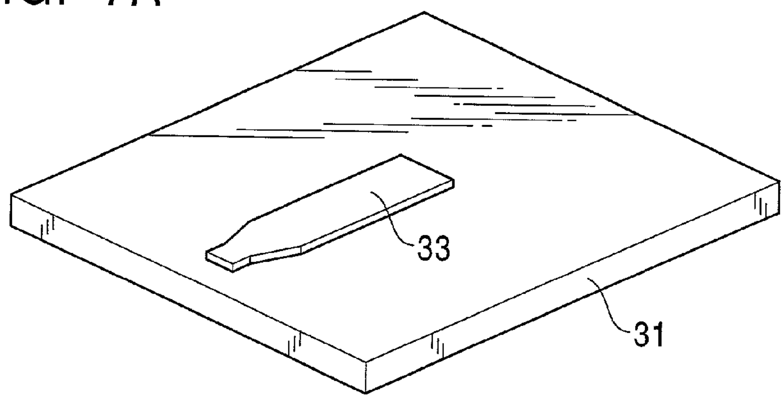


FIG. 7B

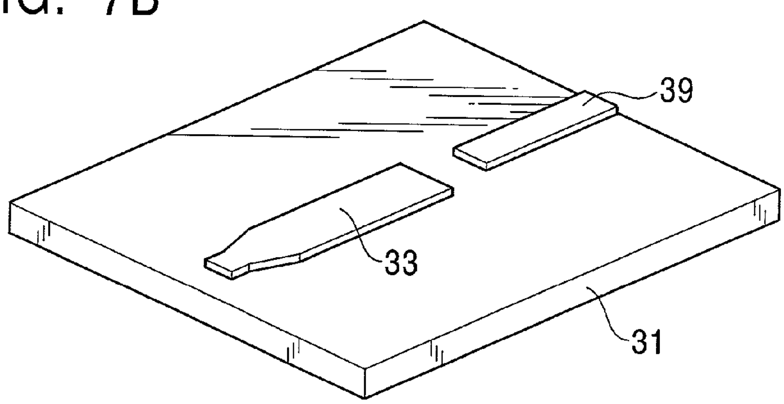


FIG. 7C

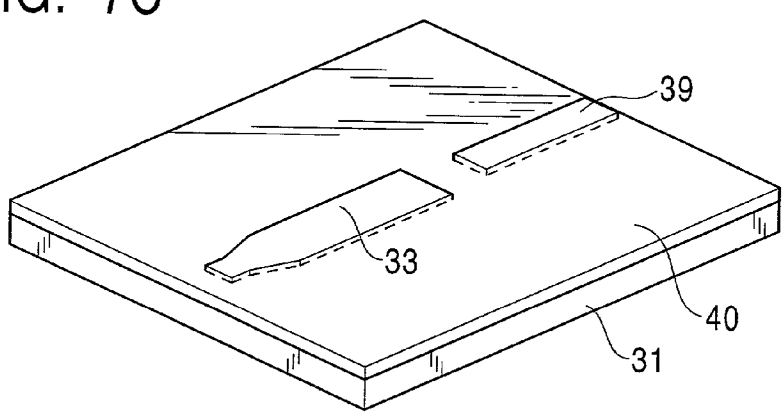


FIG. 8D

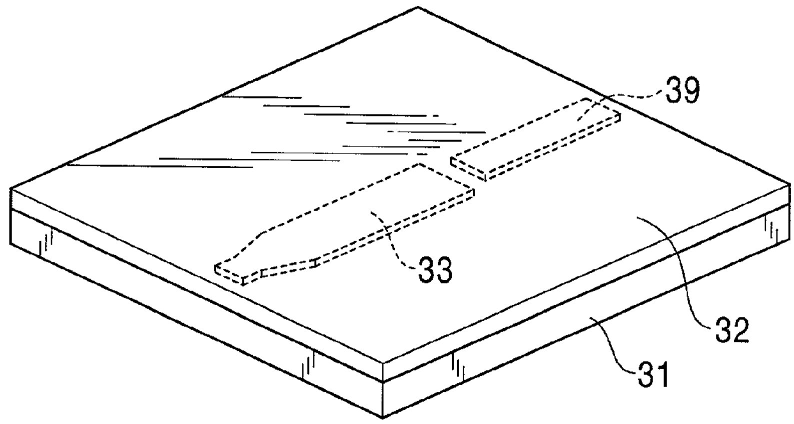


FIG. 8E

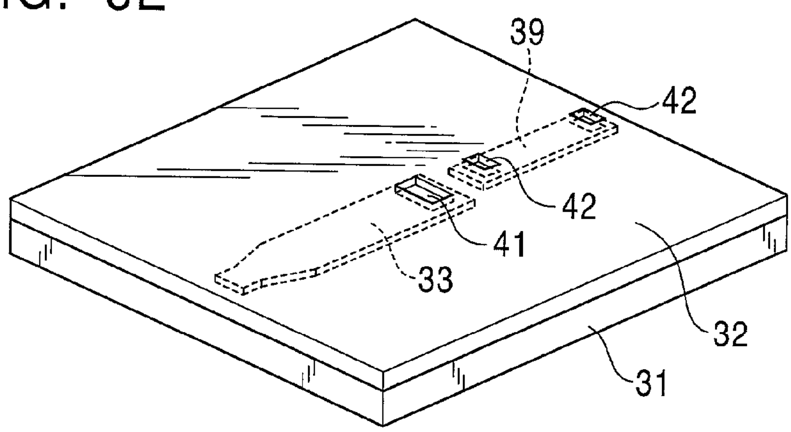


FIG. 8F

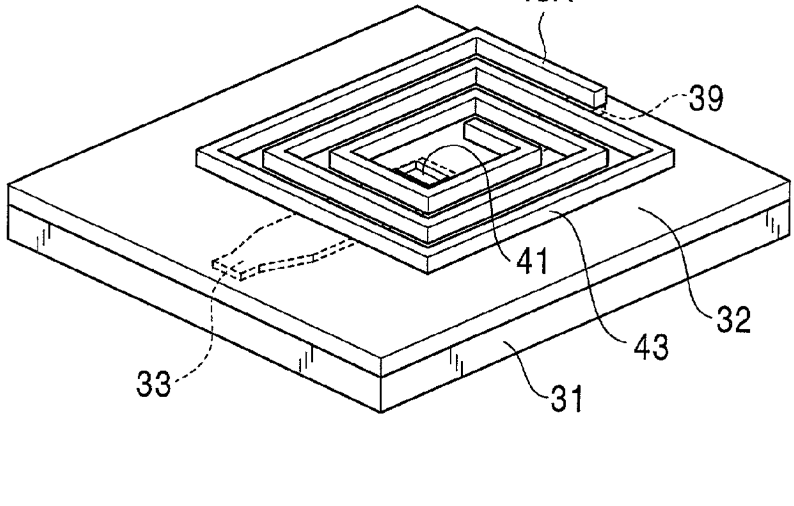


FIG. 9G

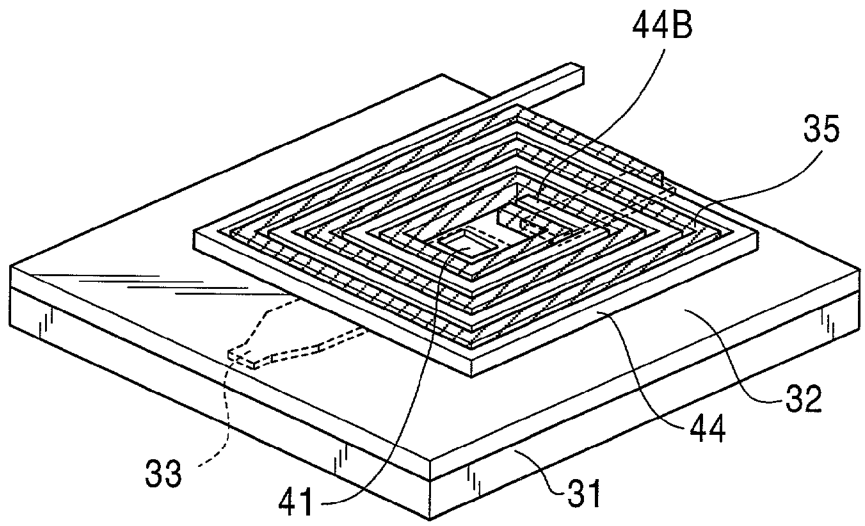


FIG. 9H

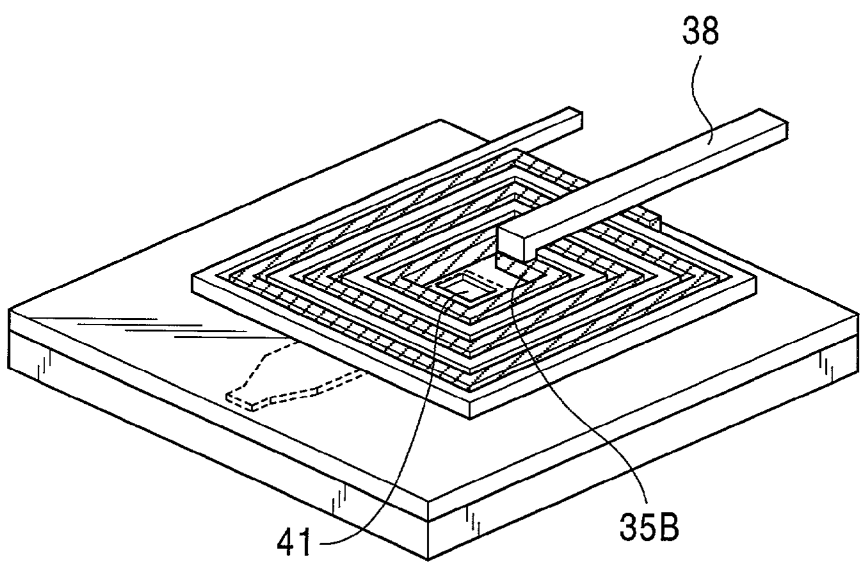


FIG. 10

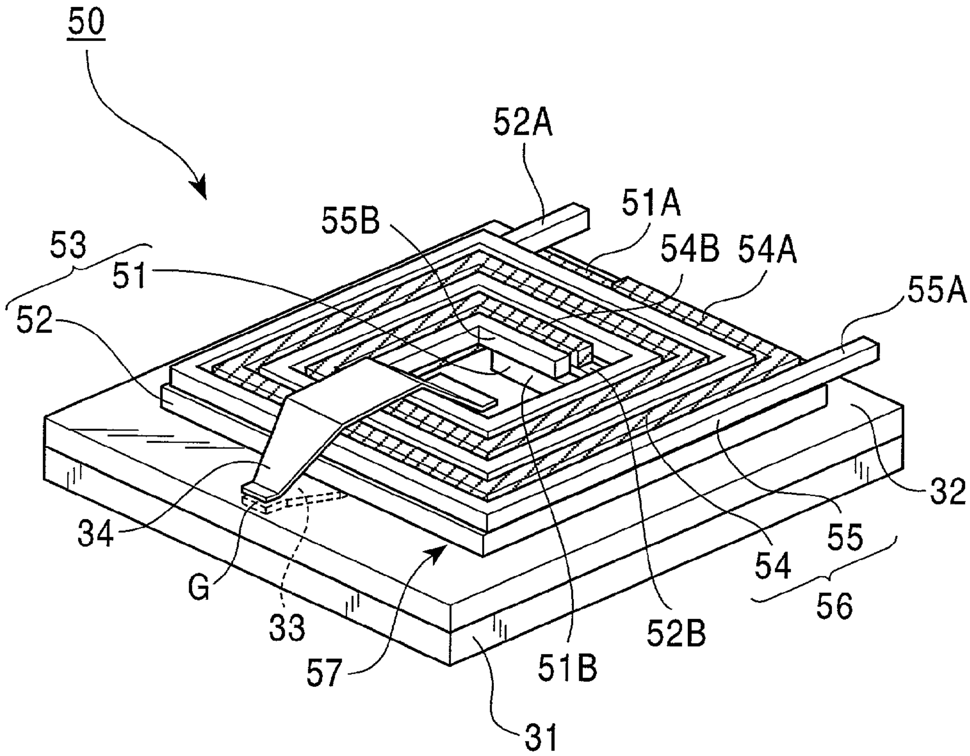


FIG. 11A

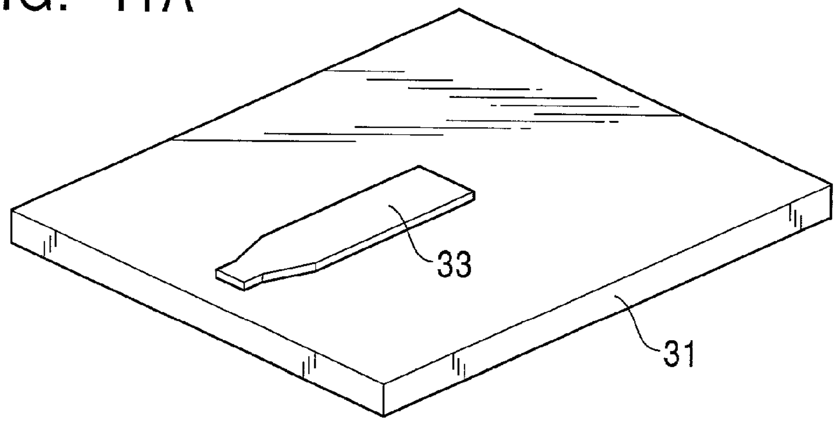


FIG. 11B

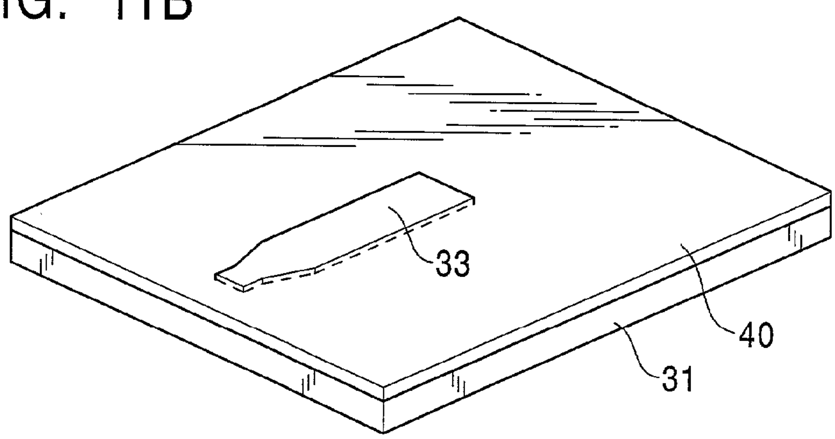


FIG. 11C

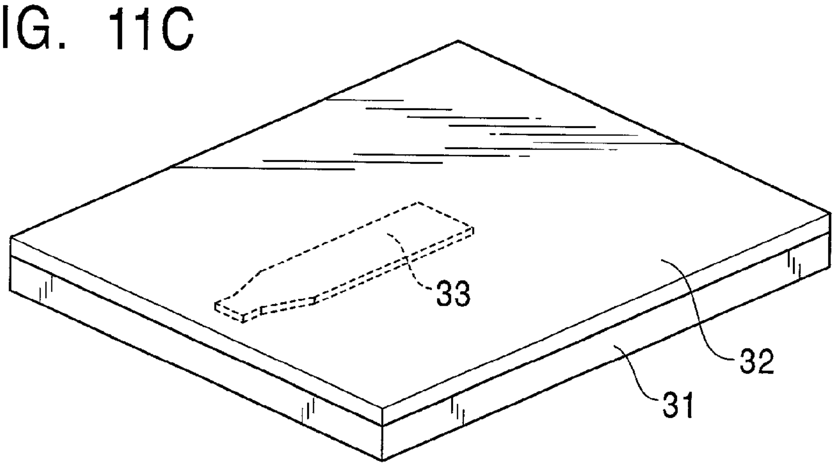


FIG. 12D

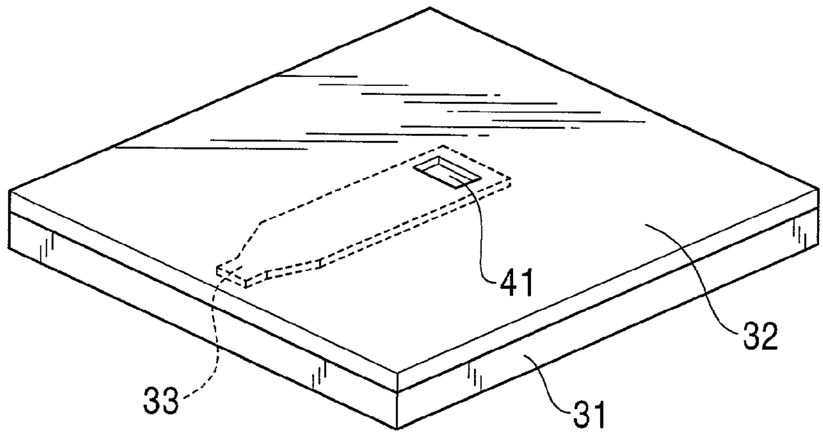


FIG. 12E

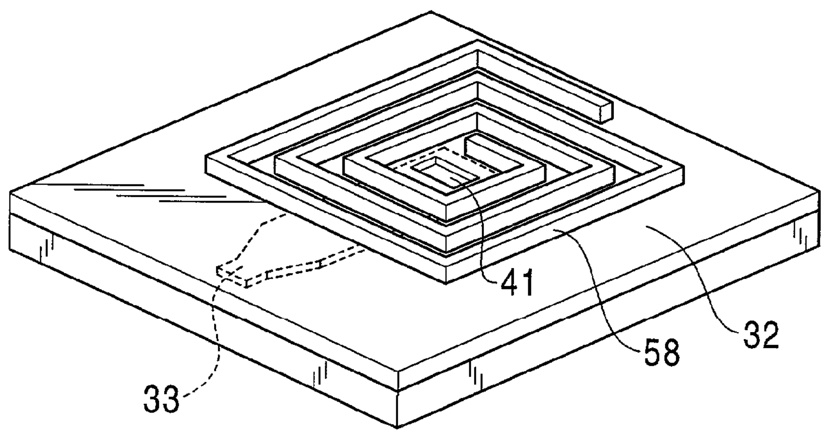


FIG. 12F

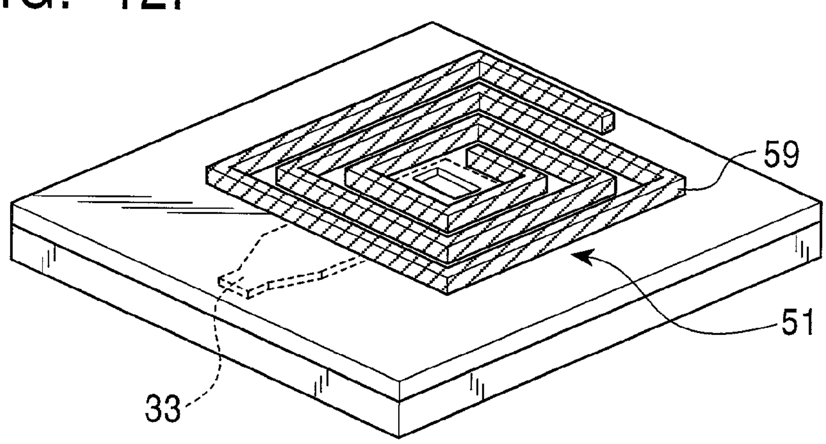


FIG. 13G

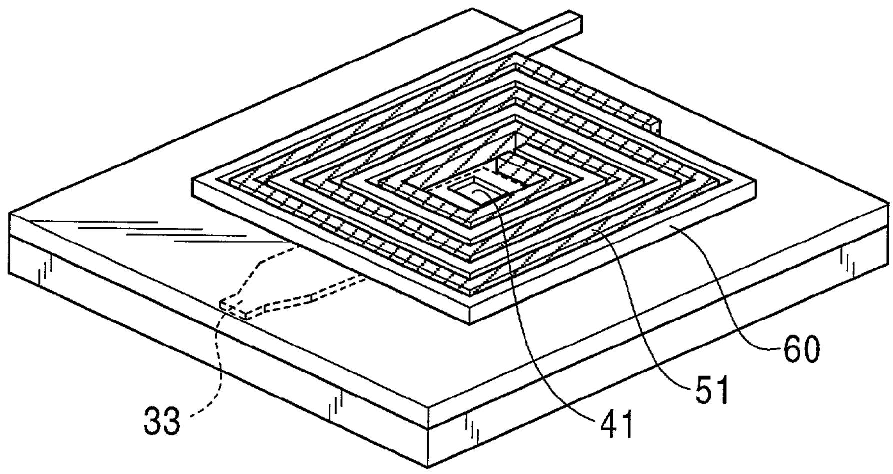


FIG. 13H

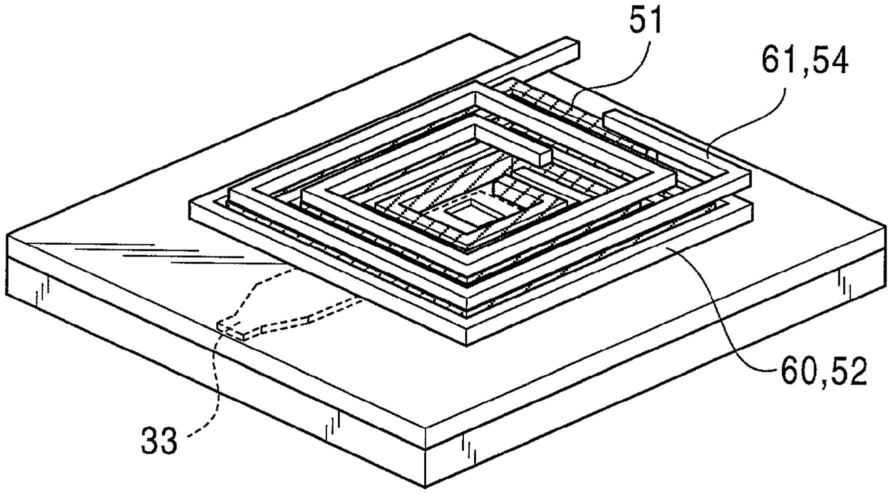


FIG. 14I

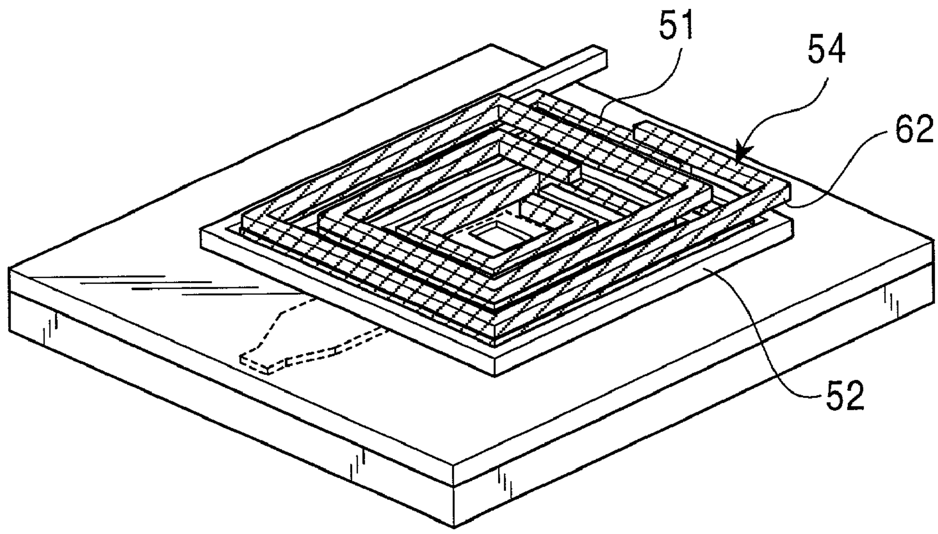


FIG. 14J

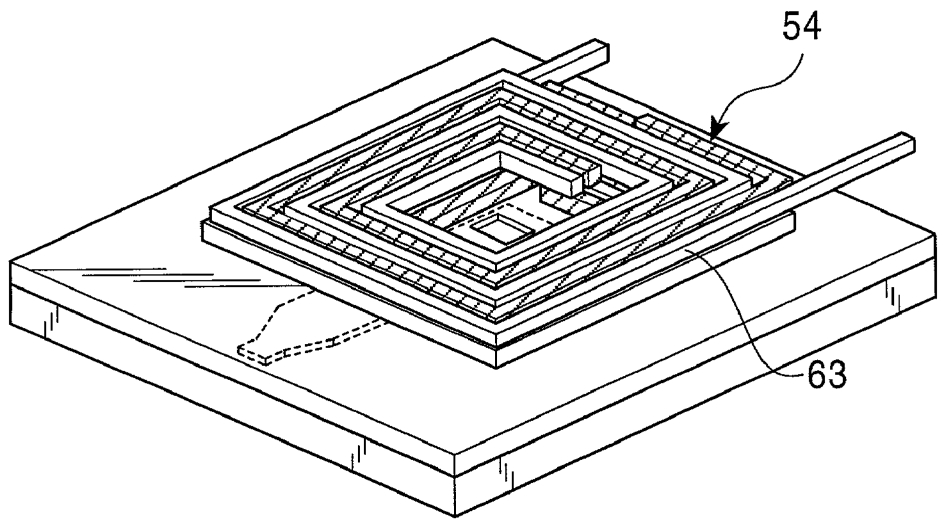


FIG. 15

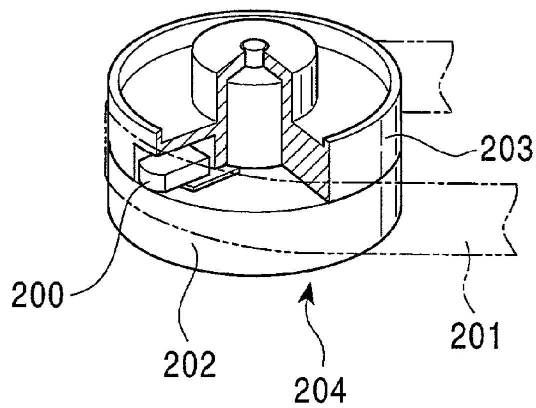


FIG. 16

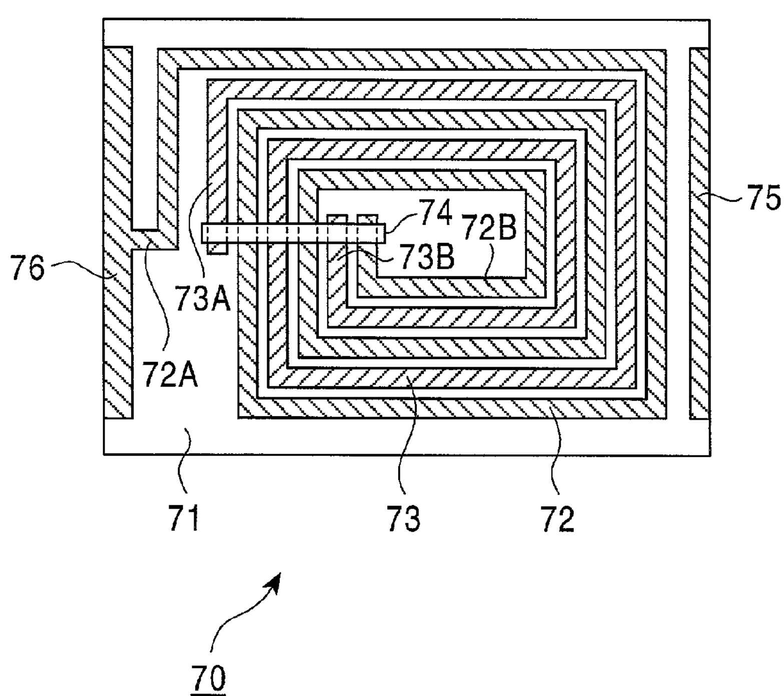


FIG. 17

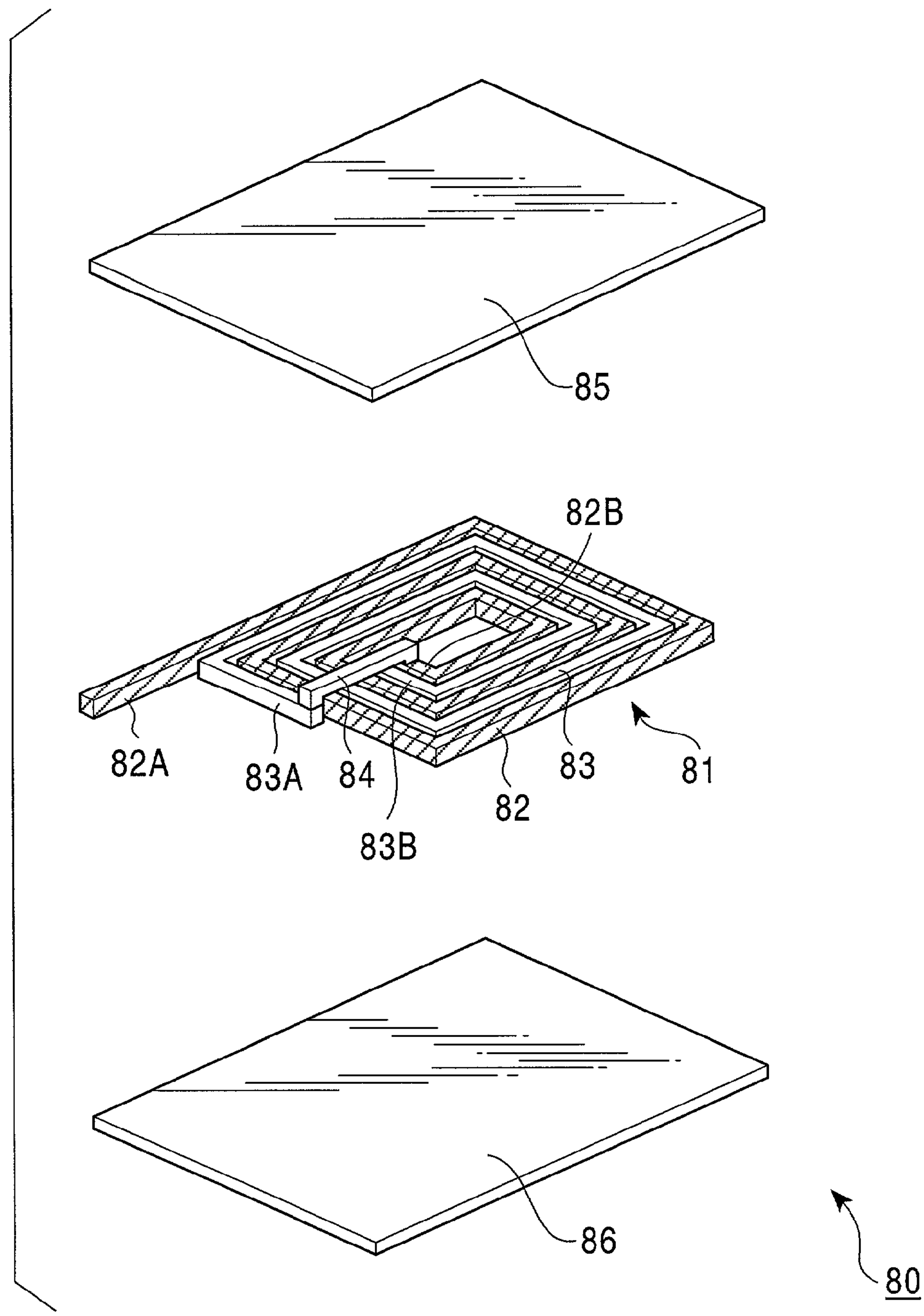


FIG. 18

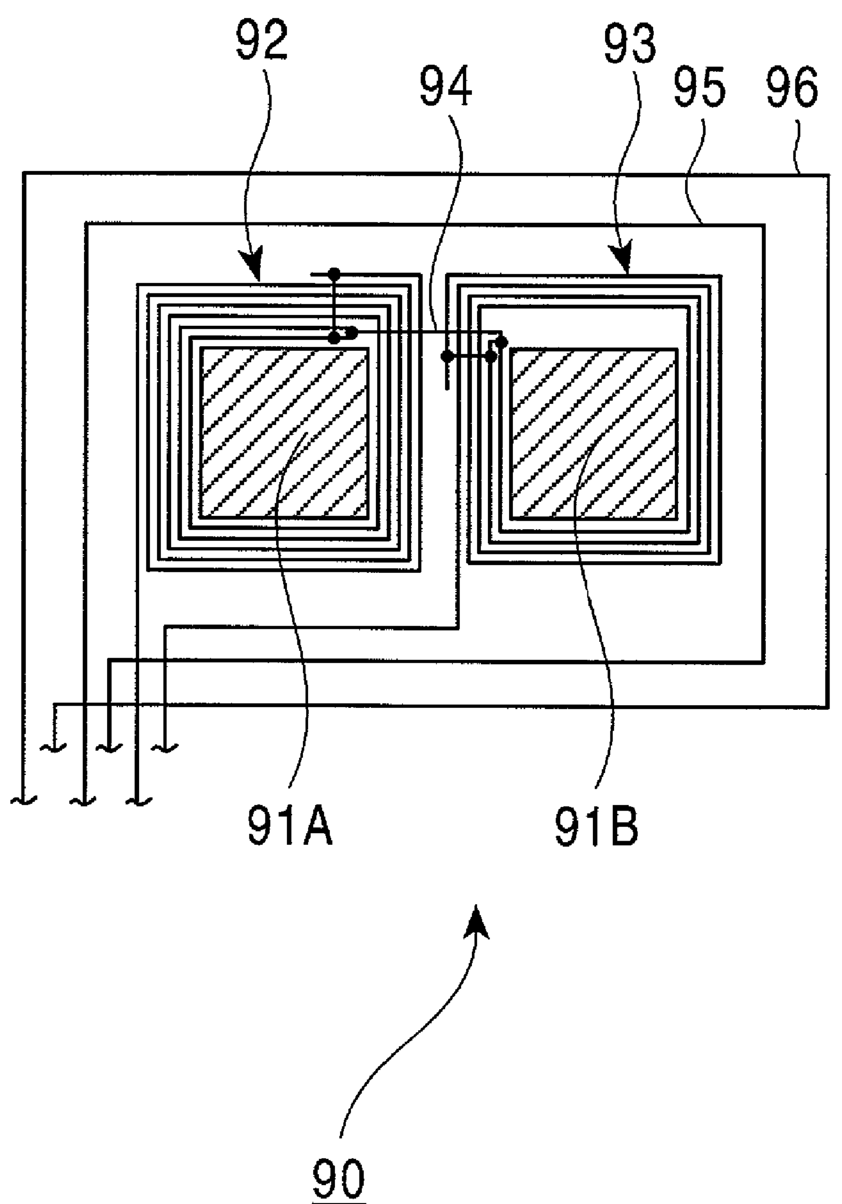


FIG. 19A

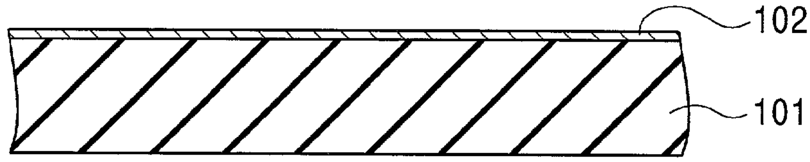


FIG. 19B

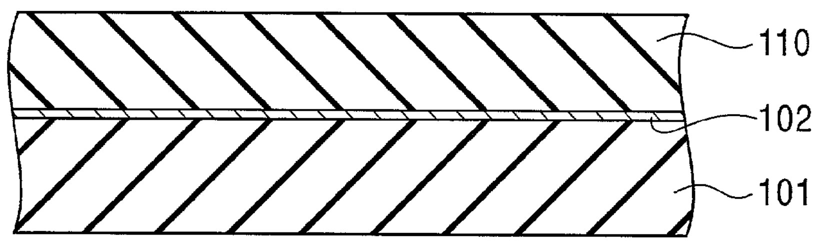


FIG. 19C

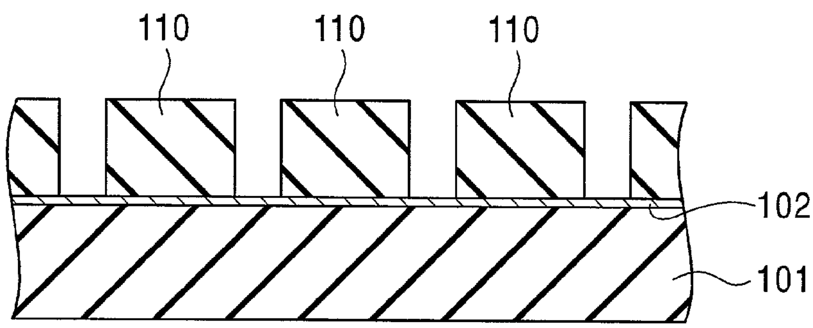


FIG. 19D

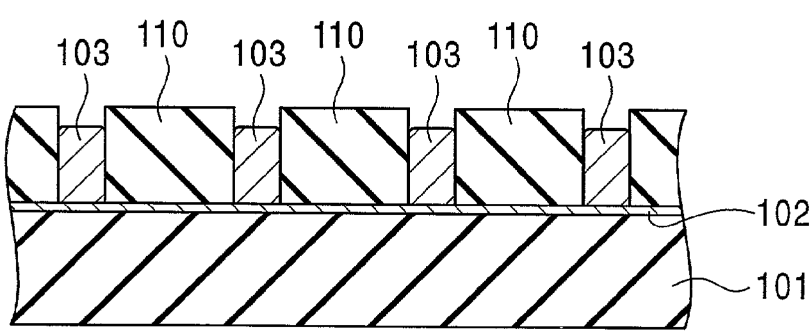


FIG. 20E

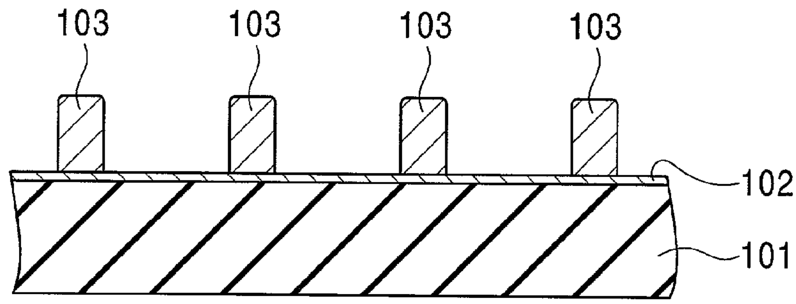


FIG. 20F

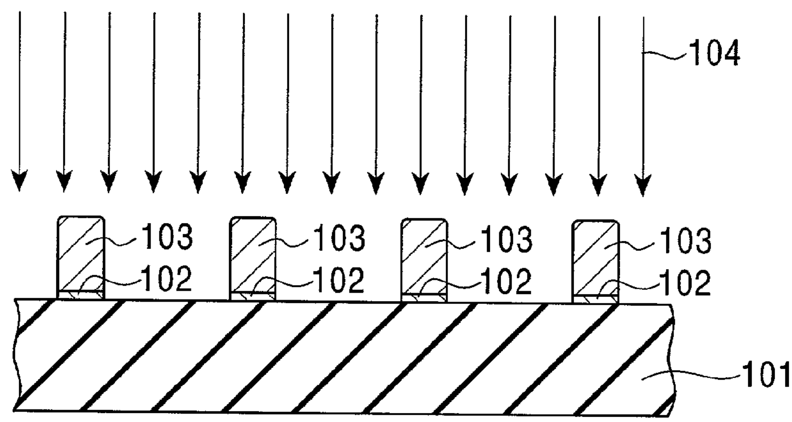


FIG. 20G

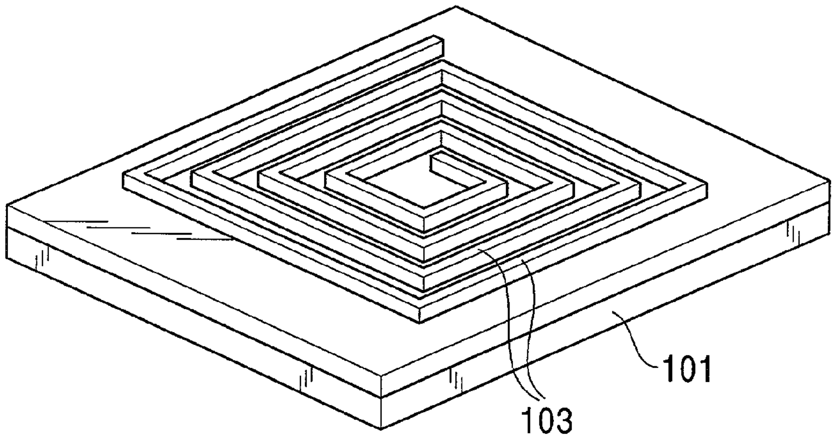


FIG. 21A

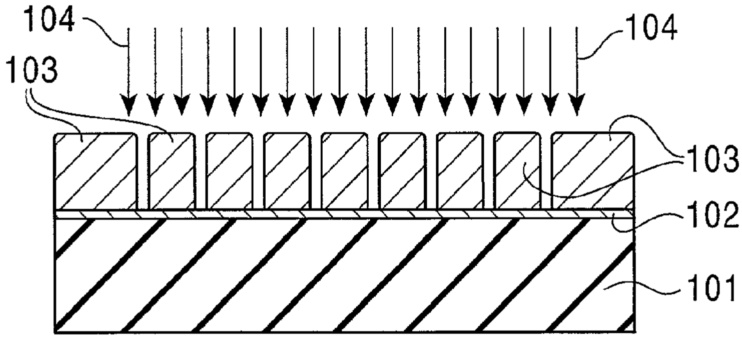


FIG. 21B

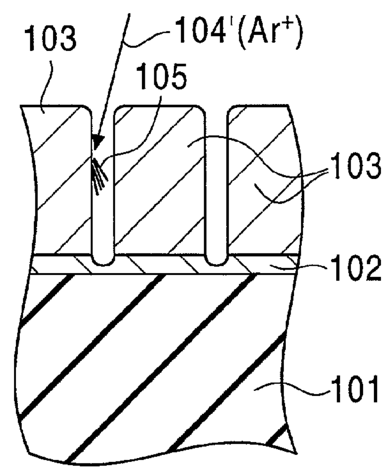
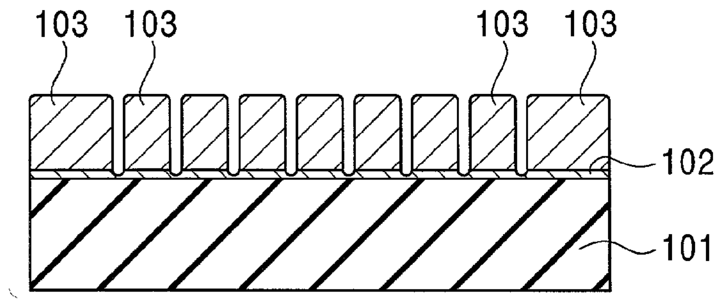


FIG. 21C



THIN FILM COIL AND METHOD OF FORMING THE SAME, THIN FILM MAGNETIC HEAD, THIN FILM INDUCTOR AND THIN FILM MAGNETIC SENSOR

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a thin film coil (thin film wiring) and a method of forming the same, and a thin film magnetic head, a thin film magnetic inductor and a thin film magnetic sensor each comprising the thin film coil.

[0003] 2. Description of the Related Art

[0004] In a so-called helical magnetic tape system, for example, a video deck magnetic head in which recording and reproduction are performed on and from a magnetic tape such as a video tape or the like, a signal recorded on the tape is detected through a rotary transformer connected to the rear stage of a coil, and thus the resistance value of the coil is restricted, thereby causing the need to decrease the DC resistance to, for example, about 3Ω or less for improving frequency response.

[0005] Furthermore, in order to respond to the radio frequency band of 200 MHz or more, the inductance must be decreased to 100 nH or less.

[0006] When a thin film inductive head having the inductance of 100 nH or less is formed by a conventional method of forming a thin film magnetic head, the magnetic core length is 50 μm or less, the polar distance 20 μm or less, and the number of coil turns is **12** is less.

[0007] A conventional method of forming a coil is shown in **FIGS. 19A** to **20**G.

[0008] First, as shown in **FIG. 19A, a** plating underlying film **102** having the same composition as a plating film, which constitutes a coil **103**, on a substrate **101**.

[0009] Next, as shown in **FIG. 19B, a** resist **110** is coated over the entire surface of the under film **102**.

[0010] Then, the resist **110** is exposed and developed to form a predetermined pattern in the resist **110**, as shown in **FIG. 19C**.

[0011] Then, as shown in **FIG. 19D, a** plating film is formed on the portions without the resist **110** by plating using the under film **102** as one of plating electrodes.

[0012] Then, as shown in **FIG. 20**E, the resist **110** is removed to leave the coil **103** comprising the plating film.

[0013] Then, in order to isolate the respective conductor turns of the coil **103** so that the coil **103** performs a predetermined operation, the under film **102** is removed from the spaces between the respective turns of the coil **103** by ion-etching **104** the under film **102** using, for example, argon ion (Ar^+), as shown in **FIG. 20F**.

[0014] As a result, the thin film coil **103** shown in a perspective view of **FIG. 20G** is formed.

[0015] The interval of the coil **103** is conventionally designed in substantially proportion to the height of the coil **103**. For example, when the height of the coil **103** is 3 μm, the interval of the conductor of the coil **103** must be set to about 2 μm.

[0016] Therefore, under the above-described conditions in which the magnetic core length is 50 μm or less, and the number of turns is **12** or less, the interval of the conductor or the coil **103** can be increased to only about 2 μm, and thus the coil height in the magnetic head is limited to about 3 μm

[0017] In this case, the DC resistance of the coil **103** is never 7Ω or less in any design.

[0018] Therefore, in order to decrease the resistance of the coil **103**, it is necessary to further increase the thickness of the coil **103**, and decrease the interval of the coil **103** to widen the coil **103**.

[0019] For example, when the coil **103** has a height of 6 μm and an interval of 1 μm, the resistance of the coil can be decreased by sufficiently increasing the height/interval ratio of the coil **103** from the value (3/2) of the above case.

[0020] However, in this case, when the under film **102** is removed by etching after the plating film of the coil **103** is plated, the under film **102** cannot be completely removed to cause the problem of failing to accurately form the coil **103**.

[0021] Namely, as shown in **FIG. 21**A, in ion etching **104**, for example, with argon ions Ar^+ for removing the under film **102** from the substrate **101**, particles **104**' (Ar^+) scattered from parallel beams of the argon ions are applied to the sides of the coil **103** comprising the plating film to emit the metal material of the coil **103**, for example, Cu **105**, as shown in **FIG. 21B**. Namely, the sides of the coil **103** are cut, and the emitted Cu **105** is again adhered (deposited) on the under film **102** at the bottom.

[0022] Furthermore, the coil **103** is thickened to make it difficult for the argon ion molecules to approach the under film **102**. Therefore, the re-adhesion of copper to the under layer **102** is dominant over etching of the under film **102**, thereby causing difficulties in removing the under film **102**.

[0023] Therefore, as shown in **FIG. 21***c*, the under film **102** cannot be completely removed from the spaces between the respective turns of the coil **103** to leave the under film **102** in these spaces, thereby failing to isolate the respective turns of the coil **103** to short-circuit the coil **103**.

[0024] Therefore, a small thin film inductive head having a resistance value of as low as about 2Ω cannot be formed.

SUMMARY OF THE INVENTION

[0025] In order to solve the above problem, an object of the present invention is to provide a thin film coil having low resistance and low inductance and a method of forming the same, and a thin film magnetic head, a thin film inductor and a thin film magnetic sensor each comprising the thin film coil.

[0026] A thin film coil of the present invention comprises at least a first coil and a second coil formed on a same substrate and each comprising a conductor thin film, wherein at least the side surfaces of the conductor of the first coil are completely covered with an insulating film, and the conductor of the second coil is formed on the substrate with the insulating film formed therebetween.

[0027] In the thin film coil of the present invention having the above construction, the entire side surfaces of the first coil are covered with the insulating film to insulate the conductor of the first coil from the conductor of the second coil, thereby permitting the formation of the first and second coils with narrow gaps therebetween.

[0028] A method of forming a thin film coil of the present invention comprises the step of forming a plating underlying film on a substrate, the step of depositing a conductor of a thin film coil in a predetermined pattern by plating on the plating underlying film, the step of etching off the plating underlying film except the portion below the conductor to form a first coil of the thin film coil, the step of forming an insulating film over the entire surface, the step of forming a second plating underlying film on the insulating film, the step of forming a conductor of a second coil of the thin film coil in a predetermined pattern by plating on the portion of the second plating underlying film, which corresponds to the pitch interval of the first coil, and the step of removing the second plating underlying film on the insulating film of the first coil.

[0029] In the method of forming a thin film coil of the present invention, the first coil is formed, and then the insulating film is formed over the entire surface of the first coil to insulate the conductor of the first coil. The conductor of the second coil is formed on the second plating underlying film formed on the insulating film to form a structure in which the conductors of the first and second coils are not connected to each other. Also, the second plating underlying film formed on the insulating film of the first coil is removed to cut off the second plating underlying film which continues in the spaces between the respective turns of the conductor of the second coil, thereby separating the respective turns of the conductor of the second coil.

[0030] Therefore, the thin film coil can be formed, in which the turns of the conductors of the first and second coil are separated from each other.

[0031] A thin film magnetic head of the present invention comprises a thin film coil comprising at least a first coil and a second coil formed on a same substrate, and two magnetic cores arranged with the thin film coil held therebetween and a magnetic gap held between the tip portions thereof, wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film, and the conductor of the second coil is formed on the substrate with the insulating film provided therebetween.

[0032] In the thin film magnetic head of the present invention having the above construction, the magnetic cores are arranged with the thin film coil of the present invention provided therebetween, thereby narrowing the interval of the conductor of the thin film coil. Therefore, the resistance can be decreased by, for example, thickening the thin film coil, a magnetic field produced in the magnetic cores can be strengthened by, for example, increasing the number of turns of the thin film coil with the same area, and the area of the thin film coil can be decreased, for example, with the same number of turns.

[0033] A thin film inductor of the present invention comprises a thin film coil comprising at least a first coil and a second coil formed on a same substrate, wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film, the conductor of the second coil is formed on the substrate with the insulating film formed therebetween, the first coil and the second coil of the thin film coil are electrically connected to each other, and one end of the thin film coil is connected to the outside, the other end being a free end.

[0034] In the thin film inductor of the present invention having the above construction, magnetic cores are arranged with the thin film coil of the present invention provided therebetween, thereby narrowing the interval of the conductor of the thin film coil. Therefore, the resistance can be decreased by, for example, thickening the thin film coil, and the number of turns of the thin film coil can be increased, for example, with the same area.

[0035] A thin film magnetic sensor of the present invention comprises a thin film coil comprising at least a first coil and a second coil formed on a same substrate, wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film, and the conductor of the second coil is formed on the substrate with the insulating film formed therebetween.

[0036] In the thin film magnetic sensor of the present invention having the above construction, magnetic cores are arranged with the thin film coil of the present invention provided therebetween, thereby narrowing the interval of the conductor of the thin film coil. Therefore, the resistance can be decreased by, for example, thickening the thin film coil, and the number of turns of the thin film coil can be increased, for example, with the same area.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] **FIG. 1** is a schematic drawing (perspective view) of the construction of a thin film coil according to an embodiment of the present invention;

[0038] **FIG. 2** is a sectional view taken along line II-II in **FIG. 1**;

[0039] **FIGS. 3A** to 3C are drawings showing the steps of a method of forming the thin film coil shown in **FIG. 1**;

[0040] **FIGS. 4D** to 4F are drawings showing the steps of the method of forming the thin film coil shown in **FIG. 1**;

[0041] **FIGS. 5G** to 5I are drawings showing the steps of the method of forming the thin film coil shown in **FIG. 1**;

[0042] **FIG. 6** is a schematic drawing (perspective view) of the construction of a thin film magnetic head according to another embodiment of the present invention;

[0043] **FIGS. 7A** to 7C are drawings showing the steps of a method of forming the thin film magnetic head shown in **FIG. 6**;

[0044] **FIGS. 8D** to 8F are drawings showing the steps of the method of forming the thin film magnetic head shown in FIG. **6**;

[0045] **FIGS. 9G and 9H** are drawings showing the steps of the method of forming the thin film magnetic head shown in **FIG. 6**;

[0046] **FIG. 10** is a schematic drawing (perspective view) of the construction of a thin film magnetic head according to still another embodiment of the present invention;

[0047] **FIGS. 11A** to **11**C are drawings showing the steps of a method of forming the thin film magnetic head shown in **FIG. 10**;

[0048] **FIGS. 12D** to **12**F are drawings showing the steps of the method of forming the thin film magnetic head shown in **FIG. 10**;

[0049] **FIGS. 13G and 13H** are drawings showing the steps of the method of forming the thin film magnetic head shown in **FIG. 10**;

[0050] **FIGS. 14I and 14J** are drawings showing the steps of the method of forming the thin film magnetic head shown in **FIG. 10**;

[0051] **FIG. 15** is a drawing showing the construction of a drum unit comprising a helical scanning magnetic head;

[0052] **FIG. 16** is a drawing showing a thin film magnetic head according to a further embodiment of the present invention;

[0053] **FIG. 17** is a drawing showing a thin film inductor according to a still further embodiment of the present invention;

[0054] **FIG. 18** is a drawing showing a thin film magnetic sensor according to a further embodiment of the present invention;

[0055] **FIGS. 19A** to **19**D are drawings showing the steps of a conventional method of forming a thin film magnetic head;

[0056] **FIGS. 20E** to **20**G are drawings showing the steps of the conventional method of forming a thin film magnetic head; and

[0057] **FIGS. 21A** to **21**C are drawings illustrating the problem of the conventional method of forming a thin film coil.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0058] The present invention provides a thin film coil comprising at least a first coil and a second coil formed on a same substrate and each comprising a conductor thin film. At least the side surfaces of the conductor of the first coil are completely coated with an insulating film, and the conductor of the second coil is formed on the substrate with the insulating film formed therebetween.

[0059] In the thin film coil of the present invention, the conductor of the first coil is formed on the substrate with a plating underlying film formed therebetween, and the conductor of the second coil is formed on the insulating film with a plating underlying film formed therebetween.

[0060] The present invention also provides a method of forming a thin film coil comprising the step of forming a plating underlying film on a substrate, the step of depositing a conductor of a thin film coil in a predetermined pattern by plating on the plating underlying film, the step of etching off the plating underlying film except the portion below the conductor to form a first coil of the thin film coil, the step of forming an insulating film over the entire surface, the step of forming a second plating underlying film on the insulating film, the step of forming a conductor of a second coil of the thin film coil in a predetermined pattern by plating on the portion of the second plating underlying film, which corresponds to the pitch interval of the first coil, and the step of removing the second plating underlying film on the insulating film of the first coil.

[0061] The present invention further provides a thin film magnetic head comprising a thin film coil comprising at least a first coil and a second coil formed on a same substrate, and two magnetic cores arranged with the thin film coil held therebetween and a magnetic gap held between the tip portions thereof, wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film, and the conductor of the second coil is formed on the substrate with the insulating film formed therebetween.

[0062] The present invention further provides a thin film inductor comprising a thin film coil comprising at least a first coil and a second coil formed on a same substrate, wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film, the conductor of the second coil is formed on the substrate with the insulating film formed therebetween, the first coil and the second coil of the thin film coil are electrically connected to each other, and one end of the thin film coil being connected to the outside, the other end being a free end.

[0063] The present invention further provides a thin film magnetic sensor comprising a thin film coil comprising at least a first coil and a second coil formed on a same substrate, wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film, and the conductor of the second coil is formed on the substrate with the insulating film formed therebetween.

[0064] **FIG. 1** is a drawing (perspective view) showing the construction of a thin film coil according to an embodiment of the present invention.

[0065] The thin film coil **10** shown in **FIG. 1** comprises a first coil **11** (**11**A and **11**B) and a second coil **12** (**12**A and **12**B), which are spirally formed on a substrate **1**. The first coil **11** is arranged inward of the second coil **12**, and the two coils **11** and **12** are formed with a narrow gap therebetween. In **FIG. 1**, the first coil **11** is discriminated from the second coil **12** by shadowing.

[0066] The ends of the first and second coils **11** and **12**, for example, the external end **11**A of the first coil **11** and the internal end **12**B of the second coil **12**, are electrically connected through wiring or the like to form the thin film coil **10** comprising the first and second coils **11** and **12** formed with a narrow gap therebetween.

[0067] The wiring may be provided above or below the conductors of the coils **11** and **12** through an insulator except in a contact portion.

[0068] As the material for the thin film coil **10**, a low-resistance metal material such as copper, gold, silver, platinum, aluminum, or an alloy containing these metals can be used.

[0069] Particularly, copper can easily be plated, and is thus suitable as the material for the thin film coil **10**.

[0070] **FIG. 2** is a sectional view taken along line II-II in **FIG. 1**.

[0071] The first coil 11 comprises a conductor coil 14 formed on the substrate 1 with an under film 13 provided therebetween, the upper and side surfaces of the conductor 14 being completely coated with an insulating film 15.

[0072] The second coil 12 comprises the insulating film 15 formed on the substrate to cover the conductor 14 of the first coil 11, an under film 16 formed on the insulating film 16, and a coil conductor 17 formed on the under film 16. The under film 16 is also formed on the insulating film 15 on the side surfaces of the first coil 11.

[0073] The under films 13 and 16 are left as electrodes for forming the conductors 14 and 17 of the coils by plating, and made of the same material as the conductors 14 and 17.

[0074] Although the material for the insulating film 15 is not limited, for example, alumina (Al_2O_3) can be used.

[0075] In the thin film coil 10 of this embodiment having the above construction, the conductor 14 of the first coil 11 is insulated from the conductor 17 of the second coil 12 by the insulating film 15 for each turn.

[0076] Also, the gap between the first coil 11 and the second coil 12 is very narrow, and thus the gap between the conductors 14 and 17 is also narrow in comparison to the width of the conductors 14 and 17. Therefore, only the insulating film 15, the under film 16 and the small gap are present between the conductors 14 and 17.

[0077] The method of forming the thin film coil 10 of this embodiment will be described below.

[0078] First, as shown in FIG. 3A, the conductor 14 of the first coil 1 is formed by plating on the substrate 1 with the under film 13 formed therebetween. The conductor 14 is formed at an interval corresponding to the portion in which the second coil 12 is later formed.

[0079] The state shown in FIG. 3A is obtained according to the steps of the conventional forming method shown in FIGS. 19A to 20E.

[0080] Next, as shown in FIG. 3B, the under film 13 is etched off except the portions below the conductor 14. Etching can be performed by ion etching, for example, with above-described argon ions (Ar^+).

[0081] Next, as shown in FIG. 3C, the insulating film 15 made of, for example, alumina is formed over the entire surface of the conductor 14. In this step, in the portions where the second coil 12 is later formed, the surface of the substrate 1 is coated with the insulating film 15.

[0082] Then, as shown in FIG. 4D, the plating underlying film 16 is deposited over the entire surface of the insulating film 15.

[0083] Next, as shown in FIG. 4E, a resist 21 is coated over the entire surface of the under film 16.

[0084] Then, the resist 21 is patterned in a predetermined pattern by exposure and development, as shown in FIG. 4F. In this step, the resist 21 is thinly left on the side surfaces of the first coil 11.

[0085] Next, as shown in FIG. 15G, the coil conductor 17 of the second coil 12 is formed in the recesses of the resist 21 by plating using the under film 16 as an electrode.

[0086] Then, as shown in FIG. 15H, the resist 21 is removed. In this step, narrow gaps are formed between the side surfaces of the first coil and the conductor 17 of the second coil 12.

[0087] Furthermore, as shown in FIG. 5I, the under film 16 on the surface of the fist coil 11 is removed by etching, for example, the above-described ion etching. As a result, the turns of the conductor 17 of the second coil 12 are isolated from each other.

[0088] Then, an insulating film for covering the entirety, and wiring are formed to complete the thin film coil.

[0089] In this way, the thin film coil 10 shown in FIGS. 1 and 2 can be formed.

[0090] The construction of the thin film coil 10 of this embodiment can be applied to a case in which a coil conductor is formed by a method other than plating. In this case, the under films 13 and 16 shown in FIG. 2 are not formed, and thus the conductors 14 and 17 are formed on the substrate 1 and the insulating film 15, respectively. In this case, the conductor 14 can be insulated from the conductor 17 through the insulating film 15.

[0091] However, particularly when the thickness of the coil is increased as compared with the width, i.e., when the aspect ratio of the coil is increased, the aspect ratio of the recesses in which the coil conductor is formed is increased. Therefore, formation of the conductor by plating has the advantage that a good film can easily be formed.

[0092] Although, in this embodiment, the entire upper surface of the conductor 14 of the first coil 11 is coated with the insulating film 15, the entire upper surface of the conductor 14 needs not necessarily to be coated with the insulating film.

[0093] Even when at least the side surfaces of the conductor 14 are coated with the insulating film 15 to leave a portion of the upper surface conductor 14 uncoated with the insulating film 15, the thin film can be operated as a thin film coil as long as insulation of the conductor 14 from the under film 16 for the second coil 12 is secured.

[0094] In the thin film coil 10 of this embodiment, the upper and side surfaces of the conductor 14 of the first coil 11 are coated with the insulating film 15, and the conductor 17 of the second coil 12 is formed on the substrate 1 through the same insulating film 15 as the first coil 11, thereby securely insulating the conductors 14 and 17 of the coil 10 by the insulating film 15.

[0095] Therefore, even when the two coils 11 and 12 are formed with a narrow gap therebetween, each of the conductors 14 and 17 is insulated to cause no leakage, thereby permitting a reduction in the coil pitch as compared with a conventional coil. For example, the coil pitch can be decreased to 1.5 μm or less.

[0096] Also, even when the coil is thickened, each of the conductors 14 and 17 is insulated. Therefore, the coil can be thickened to, for example, a thickness of 4 μm or more, as compared with a conventional coil.

[0097] Therefore, the aspect ratio (coil height/coil width) of the coil can easily be increased to, for example, 3 or more, and the thickness of the coil can be increased to decrease the resistance and inductance of the coil.

[0098] Furthermore, the conductors are securely insulated from each other by the insulating film **15**, thereby improving the yield of formation of the coil.

[0099] Like the thin film coil **10** of this embodiment, the thin film coil of the present invention can be applied to various devices each comprising the thin film coil.

[0100] Applications of the present invention will be described with reference to embodiments.

[0101] **FIG. 6** is a schematic drawing (perspective view) showing an inductive thin film magnetic head in accordance with another embodiment of the present invention.

[0102] The thin film magnetic head **30** shown in **FIG. 6** comprises a magnetic gap (recording gap) G formed between the tip portions of a lower magnetic core layer **33** and an upper magnetic core layer **34**, and a thin film coil **37** provided in an intermediate portion between the lower and upper magnetic core layers **33** and **34**.

[0103] The thin film coil **37** comprises first and second oil **35** and **36** having the same construction as the thin film coil **10** shown in **FIGS. 1 and 2**. In **FIG. 6**, wiring **38** is connected to the internal end **35**B of the first coil **35**, and connection wiring **39** is connected to the external end **35**A of the first coil **35** and the internal end **36**B of the second coil **26**, as shown by broken line. This connection permits a current to flow through the first and second coils **35** and **36** in the same direction, thereby intensifying the magnetic fluxes produced by the current by each other.

[0104] This construction is formed on a substrate **31**, and an insulating film **32** also used as a magnetic gap film is formed between the thin film coil **37** and the substrate **31**.

[0105] The thin film magnetic head **30** can be formed, for example, as described below.

[0106] First, as shown in **FIG. 7**A, for example, permalloy (Ni—Fe alloy) is plated on the substrate **31** comprising, for example, an altic substrate to form the lower magnetic core layer **33** having a thickness of, for example, 3 μm.

[0107] Then, as shown in **FIG. 7**B, the connection wiring **39** is formed behind the lower magnetic core layer **33**, for connecting the two coils **35** and **36** of the thin film coil **37**.

[0108] Next, an alumina film **40** is deposited to a thickness of, for example, 5 μm over the entire surface by sputtering, and then the lower magnetic core layer **33** and the periphery thereof are planarized by mechanical polishing, as shown in **FIG. 7C**. This processing is performed for simplifying the subsequent steps. Namely, the lower magnetic core layer **33** and the connection wiring **39** are exposed from the surface of the alumina film **40** by planarization.

[0109] Next, for example, an alumina film is deposited as a gap film to a thickness of 0.5 μm over the entire surface. As a result, as shown in **FIG. 8D**, the lower magnetic core layer **33** and the connection wiring **39** are coated with the alumina film. **FIG. 8D** shows an insulating film **32** comprising an alumina film including the previously-formed alumina film **40** and the gap film.

[0110] Then, as shown in **FIG. 8**E, the gap film (the insulating film **32**) is removed from the portion above the rear end of the lower magnetic core layer **33** and the portions above both ends of the connecting wiring **39**, for forming a back gap hole **41** for connecting upper and lower poles, and connecting holes **42** for contact with the connection wiring **39**.

[0111] The gap film may be removed by physical etching such as ion etching, or dissolution in an alkali solution.

[0112] Next, as shown in **FIG. 8**F, the conductor **43** of the first coil **35** of the thin film coil **37** is formed on the insulating film **32**. First, a plating underlying film is deposited on the insulating film **32**, and then a resist (not shown in the drawing) is patterned in the shape of the thin film coil according to the above-described method of forming a thin film coil.

[0113] In this step, the resist is patterned so that among the conductors of the final thin film coil **37**, the conductor of the first coil **35** is formed alternately in order to facilitate etching of the under film.

[0114] In this way, the conductor **43** of the first coil **35** comprising a plated film is formed. The conductor **43** is formed so that one end **43**A fills the rear end-side connection hole **42** of the connection wiring **39**, thereby achieving electrical connection between the conductor **43** of the first coil **35** and the connection wiring **39**.

[0115] Next, the resist is separated with a solvent, for example, acetone, and then the under film is removed by an ion etching apparatus except the portions below the conductor **43**.

[0116] Then, an insulating film (corresponding to the insulating film **15** shown in **FIG. 2**) comprising, for example, an alumina film, is deposited to a thickness of, for example, 0.2 μm to cover the conductor **43**, forming the first coil **35** of the thin film coil **37**.

[0117] Then, as shown in **FIG. 9**G, the conductor **44** of the second coil **36** of the thin film coil **37** is formed by the same method as described above.

[0118] First, the insulating film filling the front end-side connection hole **42** of the connection wiring **39** is etched off.

[0119] Next, an under film is deposited on the insulating film coated on the conductor **43** of the first coil **35**, and a resist pattern is formed on the under film to form recesses between the respective turns of the first coil **35**.

[0120] Then, the conductor **44** of the second coil **36** is formed by plating. The conductor **44** of the second coil **36** is formed so that the internal end **44**B fills in the front end-side connection hole **42** of the connection wiring **39**. As a result, electrical connection between the conductor **44** of the second coil **36** and the connection wiring **39** can be attained.

[0121] Then, the surface is polished to remove the plating underlying film formed on the upper surface of the first coil **35**, separating the respective turns of the conductor **44** of the second coil **36**.

[0122] Then, an interlayer insulating film is formed to cover the thin film coil **37** comprising the first and second coils **35** and **36**. In this step of forming the interlayer insulating film, the back gap hole **41** is masked to be avoided from being filled with the interlayer insulating film, or the interlayer insulating film formed on the back gap hole **41** is removed.

[0123] Next, as shown in **FIG. 9**H, the wiring **38** is connected to the internal end **35**B of the first coil **35** through the connection hole formed in the interlayer insulating film.

[0124] Furthermore, the upper magnetic core layer **34** is formed above the lower magnetic core layer **33** so as to fill in the back gap hole **41**. Therefore, the upper magnetic core layer **34** is connected to the lower magnetic core layer **33** through the back gap hole **41** to form a magnetic path.

[0125] In this way, the inductive thin film magnetic head **30** shown in **FIG. 60** can be produced.

[0126] Since the thin film magnetic head **30** of this embodiment comprises the thin film coil **37** having the same construction as the above-described thin film coil **10**, the distance between the conductors **43** and **44** of the thin film coil **37** can be decreased, and the resistance and inductance can be decreased by increasing the thickness of the thin film coil **37**.

[0127] Therefore, the thin film coil **37** can be formed with a high density, and the number of turns of the thin film coils **37** can be increased with the same area. Therefore, the magnetic flux density can be increased to improve the efficiency of electromagnetic transformation.

[0128] Also, since the thickness of the thin film coil **37** can be increased, the horizontal sectional area of the thin film coil **37**, which is necessary for passing the same current, can be decreased, and the interval of the thin film coil **37** can also be decreased.

[0129] Therefore, the area of the thin film coil **37** can be decreased to permit reduction in size of the magnetic cores **33** and **34**, and miniaturization of the whole size of the magnetic head **30**.

[0130] **FIG. 10** is a schematic drawing (perspective view) of the construction of an inductive thin film magnetic head in accordance with still another embodiment of the present invention.

[0131] In this embodiment, particularly a thin film soil has a two-layer structure in which each of the coil layers comprises two coils. Namely, the thin film coil comprises four coils.

[0132] The thin film magnetic head **50** shown in **FIG. 10** comprises a two-layer structure thin film coil **57** comprising a lower coil layer **53** comprising first and second coils **51** and **52**, and an upper coil layer **56** comprising first and second coil **54** and **55**.

[0133] The lower coil layer **53** and the upper coil layer **56** are arranged vertically opposite to each other with an interlayer insulating film (not shown in the drawing) provided therebetween.

[0134] Through connecting holes formed in the interlayer insulating film, the external end **54**A of the first coil **54** of the upper coil layer **56** is connected to the external end **51**A of the first coil **51** of the lower coil layer **53**, the internal end **54**B of the first coil **54** of the upper coil layer **56** is connected to the internal end **52**B of the second coil **52** of the lower coil layer **53**, and the internal end **55**B of the second coil **55** of the upper coil layer **56** is connected to the internal end **51**B of the first coil **51** of the lower coil layer **53**. The remaining external end **52**A of the second coil **52** of the lower coil layer **53** and the remaining external end **55**A of the second coil **55** of the upper coil layer **56** are extended to be connected to the outside.

[0135] As a result, the four coils **51**, **52**, **54** and **55** are electrically connected through a path of the ends, 52A-52B-54B-54A-51A-51B-55B-55A. This electrical connection permits a current to flow through the four coils **51**, **52**, **54** and **55** in the same direction, thereby strengthening the magnetic flux produced by the current.

[0136] Of the other components, the same components as the thin film magnetic head **30** shown in **FIG. 6** are denoted by the same reference numerals.

[0137] However, in this embodiment, the coils of the thin film coil **57** are connected directly, and thus no connection wiring is not formed for connecting the coils.

[0138] The thin film magnetic head **50** can be formed, for example, as described below.

[0139] First, as shown in **FIG. 11**A, for example, permalloy (Ni—Fe alloy) is plated on the substrate **31** comprising, for example, an altic substrate to form the lower magnetic core layer **33** having a thickness of, for example, 3 μm.

[0140] Next, an alumina film **40** is deposited to a thickness of, for example, 5 μm over the entire surface by sputtering, and then the lower magnetic core layer **33** and the periphery thereof are planarized by mechanical polishing, as shown in **FIG. 11B**. This processing is performed for simplifying the subsequent steps. By the planarization process, the lower magnetic core layer **33** is exposed from the surface of the alumina film **40**.

[0141] Next, for example, an alumina film for a gap film is deposited to a thickness of 0.5 μm over the entire surface to cover the lower magnetic core layer **33** with the alumina film, as shown in **FIG. 11C**. **FIG. 11C** shows an insulating film comprising the alumina films including the previously-formed alumina film **40** and the gap film.

[0142] Then, in order to form a back gap hole **41** for connecting upper and lower poles, the gap film (the insulating film **32**) is partially removed from the portion above the rear end of the lower magnetic core layer **33**, as shown in **FIG. 12D**.

[0143] The gap film may be removed by physical etching such as ion etching or dissolution in an alkali solution.

[0144] Next, as shown in **FIG. 12**E, the conductor **58** of the first coil **51** of the lower coil layer **53** is formed on the insulating film **32**.

[0145] Then, as shown in **FIG. 12**F, an insulating film **59** comprising, for example, an alumina film is deposited to a thickness of, for example, 0.2 μm to cover the conductor **58**, to form the first coil **51** of the lower coil layer **53**.

[0146] Then, as shown in **FIG. 13**G, the conductor **60** of the second coil **52** of the lower coil layer **53** is formed by the same method as described above.

[0147] In this step, an under film is deposited on the insulating film **59** formed to cover the conductor **58** of the first coil **51**, and a resist pattern is formed on the under film to form recesses between the respective turns of the first coil **51**.

[0148] Then, the conductor **60** of the second coil **52** is formed by plating.

[0149] Next, the surface is polished to remove the plating underlying film deposited on the upper surface of the first coil **51**, separating the respective turns of the conductor **60** of the second coil **52**.

[0150] Then, an interlayer insulating film (or a planarizing film) is formed to cover the lower coil layer **53** comprising the first and second coils **51** and **52**. In this step of forming the interlayer insulating film, the back gap hole **41** is masked to be avoided from being filled with the interlayer insulating film, or the interlayer insulating film formed on the back gap hole **41** is removed.

[0151] Then, a connection hole (not shown in the drawing) is formed in the insulating film formed on the conductor at the end of each of the coils **51** and **52** of the lower coil layer **53**, i.e., in the insulating film and/or the interlayer insulating film (or the planarizing film) formed to cover the conductor **58** of the first coil **51**.

[0152] Next, as shown in **FIG. 13**H, the conductor **61** of the first coil **54** of the upper coil layer **56** is formed. In this step, the conductor **61** is formed so that both ends fill in the connection holes to be electrically connected to the conductor **58** of the first coil **51** of the lower coil layer **53** or the conductor **60** of the second coil **52** thereof through the connection holes.

[0153] Next, as shown in **FIG. 14**I, an insulating film **62** comprising, for example, an alumina film is formed to cover the conductor **61** of the first coil **54** of the upper coil layer **56**. As a result, the first coil **54** of the upper coil layer **56** is formed.

[0154] Then, as shown in **FIG. 14**J, the conductor **63** of the second coil **55** of the upper coil layer **56** is formed. In this step, the conductor **63** is formed so that the internal end fills in the connection hole to be electrically connected to the conductor **58** of the first coil **51** of the lower coil layer **53** through the connection hole.

[0155] As a result, the four coils **51**, **52**, **54** and **55** of the upper and lower coil layers **53** and **56** are connected in one line.

[0156] Then, an interlayer insulating film is formed to cover the thin film coil **57** comprising the lower and upper coil layers **53** and **56**. In this step of forming the interlayer insulating film, the back gap hole **41** is masked to be avoided from being filled with the interlayer insulating film, or the interlayer insulating film on the back gap hole **41** is removed.

[0157] Furthermore, the upper magnetic core layer **34** is formed above the thin film coil **57** and the lower magnetic core layer **33** so as to fill in the back gap hole **41**. Therefore, the upper magnetic core layer **34** is connected to the lower magnetic core layer **33** through the back gap hole **41** to form a magnetic path.

[0158] In this way, the inductive thin film magnetic head **50** shown in **FIG. 10** can be produced.

[0159] Like in the thin film magnetic head **30** of the previous embodiment, in the thin film magnetic head **50** of this embodiment, the gaps between the conductors **58** and **60**, and **61** and **63** of the thin film coil can be decreased, and the thickness of the thin film coil can be increased to decrease the resistance. Therefore, the efficiency of electromagnetic transformation can be improved, and the sizes of the magnetic cores **33** and **34** can be decreased to miniaturize the whole size of the magnetic head **50**.

[0160] In the thin film magnetic head **50** of this embodiment, particularly, the thin film coil **57** has a two-layer structure comprising the lower coil layer **53** and the upper coil layer **56**, thereby causing the advantage that the number of turns of the coil can be increased with a short magnetic path and a small area, and the overwrite property of the magnetic head **50** can be improved.

[0161] The inductive thin film magnetic head may have another construction comprising a plurality of coil layers which are electrically separated from each other, and each of which comprises two coils.

[0162] The inductive thin film magnetic head **30** or **50** of the above embodiment can be used as such a helical scanning magnetic head **200** as shown in **FIG. 15**, for example.

[0163] As shown in **FIG. 15**, the magnetic head **200** for magnetic recording on a magnetic tap **201** is provided on a cylindrical drum member **204** comprising upper and lower drums **203** and **202** so that the magnetic tape **201** travels along the drum member **204** to perform magnetic recording by the magnetic head **200**.

[0164] In the inductive thin film magnetic head **30** or **50** of the above embodiment, the coil resistance is decreased to improve the efficiency of electromagnetic transformation, thereby improving the frequency responsiveness of such a helical scanning magnetic head **200**.

[0165] A further embodiment of the present invention will be described below.

[0166] In this embodiment, the thin film coil is applied to a thin film inductor.

[0167] The thin film coil applied to the thin film inductor is different from the thin film coil for a magnetic head in that one end of the thin film coil is connected to the outside, while the other end is a free end.

[0168] **FIG. 16** shows an embodiment in which the thin film coil is applied to a planar thin film inductor.

[0169] The thin film inductor **70** shown in **FIG. 16** comprises a thin film coil comprising a first coil **72** and a second coil **73** which are formed on a substrate **71**.

[0170] The external end **72**A of the first coil **72** is connected to a conductor **76** on the substrate **71** at the left end shown in **FIG. 16**, and the internal end **72**B of the first coil **72** is connected to the external end **73**A of the second coil **73** through wiring **74**, the internal end **73**B of the second coil **73** being a free end.

[0171] Also, a conductor **75** is formed on the substrate **71** at the right end opposite to the conductor **76**. The conductor **75** is not connected to the thin film coil.

[0172] **FIG. 17** shows an embodiment in which the thin film coil is applied to a laminated planar thin film inductor.

[0173] **FIG. 17** is an exploded view showing the laminated structure of the thin film inductor.

[0174] The thin film inductor **80** shown in **FIG. 17** comprises a thin film coil **81** comprising a first coil **82** and a second coil **83**.

[0175] The external end **82**A of the first coil **82** is extended to be connected to the outside, and the internal end **82**B of the first coil **82** is connected to the external end **83**A of the second coil **83** through wiring **84**, the internal end **83**B of the second coil **83** being a free end.

[0176] Furthermore, magnetic films **85** and **86** are provided above and below the thin film coil **81** through insulating films (not shown in the drawing).

[0177] Since the thin film inductor **70** or **80** comprises the thin film coil having the construction of the present invention, the coil pitch can be decreased, and the thickness of the coil can be increased to decrease the coil resistance.

[0178] By increasing the aspect ratio of the coil or decreasing the coil width to 5 μm or less, the resistance can be prevented from increasing due to a skin effect in the radio frequency region to maintain a low resistance.

[0179] Also, the thin film inductor **70** or **80** can be miniaturized by increasing the number of turns of the coil per unit area, or decreasing the area of the thin film coil.

[0180] Such a thin film inductor can be used as, for example, a micro inductor for a cellular phone.

[0181] A further embodiment of the present invention will be described below.

[0182] In this embodiment, the thin film coil of the present invention is applied to a thin film magnetic sensor.

[0183] **FIG. 18** shows the embodiment in which the thin film coil is applied to a thin film magnetic sensor.

[0184] The thin film magnetic sensor **90** shown in **FIG. 18** comprises high-permeability material films **91**A and **91**B formed as magnetic cores at two positions on a substrate not shown in the drawing, and thin film coils **92** and **93** provided around the high-permeability material films **91**A and **91**B, respectively. Each of the thin film coils **92** and **93** has the same construction as the thin film coil of the present invention, in which two coils are connected to each other, and ends of the two coils are connected through wiring **94**. Also, both coils have opposite wiring directions.

[0185] Furthermore, a receiving coil **95** and a feedback coil **96** each comprising a thin film are formed outside the thin film coils **92** and **93**.

[0186] The thin film coils **92** and **93** function as exciting coils which can produce AC magnetic fluxes in opposite directions in the high-permeability material films **91**A and **91**B when a current with a specified period is passed from the outside. The induced voltage produced in the receiving coil **95** due to the magnetic fluxes is converted into a DC voltage signal (proportional to an external measured magnetic field) by an external circuit, and further amplified to be output as a magnetic field measuring signal. A current is fed back to the feedback coil **96** through a negative feedback circuit (not shown) so as to cancel the DC magnetic fluxes produced by the measured magnetic field in the high-permeability material films **91**A and **91**B, permitting high-precision measurement of a magnetic field based on a zero method.

[0187] Namely, the thin film magnetic sensor **90** is a flux gate-type magnetic sensor comprising a thin film (refer to, for example, Japanese Unexamined Patent Application Publication No. 8-201061).

[0188] Such a thin film magnetic sensor can be used as a magnetic sensor for correcting earth magnetism, and a magnetic sensor for detecting a weak magnetic field.

[0189] The thin film magnetic sensor **90** comprises the thin film coil having the construction of the present invention, and thus the coil resistance can be decreased.

[0190] Therefore, the quantity of the current of the coil can be increased with the same applied voltage, and the applied voltage necessary for magnetically saturating the high-permeability material films **91**A and **91**B serving as the magnetic cores can be decreased.

[0191] Also, the thin film magnetic sensor **90** can be miniaturized by increasing the number of turns of the coil per unit area, or decreasing the area of the thin film coil.

[0192] The thin film coil, the thin film magnetic head, the thin film inductor and the thin film magnetic sensor of the above embodiments are typical examples, and various modifications can be made for the constructions of detailed portions,

[0193] For example, in the thin film coil, the winding direction, the number of turns of the coil, the method of connecting wiring can be changed arbitrarily.

[0194] Besides the thin film coil, the above-described method of forming a thin film coil of the present invention can be applied to formation of a metal thin film by plating or the like.

[0195] For example, in forming wiring in any one of various circuit devices by using a metal thin film, the wiring interval can be decreased.

[0196] The present invention is not limited to the above-described embodiments, and various constructions may be used in the range of the gist of the present invention.

[0197] The above-described thin film coil and the method of forming the same of the present invention permit the conductors of first and second coils of the thin film coil to be securely insulated by an insulating film.

[0198] Therefore, the coil pitch can be decreased to, for example, 1.5 μm or less, as compared with conventional coils.

[0199] Also, even when the coil thickness is increased, the conductors can be insulated, and thus the thickness of the coil can be increased to, for example, 4 μm or more, as compared with conventional coils.

[0200] Therefore, the aspect ratio (coil height/coil width) of the coil can easily be increased to, for example, 3 or more, and the thickness of the coil can be increased to decrease the coil resistance and inductance.

[0201] Furthermore, the conductors can be securely insulated by an insulating film, thereby improving the yield of coil formation.

[0202] In a thin film magnetic head, a thin film inductor, and a thin film magnetic sensor each comprising the thin film magnetic coil of the present invention, the thin film coil can be formed with a narrow interval and low resistance, and thus the thin film magnetic head, the thin film inductor, and the thin film magnetic sensor can be improved in properties (for example, electromagnetic transformation), and miniaturized.

What is claimed is:

1. A thin film coil comprising at least a first coil and a second coil formed on a same substrate and each comprising a conductor thin film;

wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film; and

the conductor of the second coil is formed on the substrate with the insulating film formed therebetween.

2. A thin film coil according to claim 1, wherein the conductor of the first coil is formed on the substrate with a plating underlying film provided therebetween, and the conductor of the second coil is formed on the insulating film with a plating underlying film provided therebetween.

3. A method of forming a thin film coil comprising:

the step of forming a plating underlying film on a substrate;

the step of depositing a conductor of a thin film coil in a predetermined pattern by plating on the plating underlying film;

the step of etching off the plating underlying film except the portion below the conductor to form a first coil of the thin film coil;

the step of forming an insulating film over the entire surface;

the step of forming a second plating underlying film on the insulating film;

the step of forming a conductor of a second coil of the thin film coil in a predetermined pattern by plating on the portion of the second plating underlying film, which corresponds to the pitch interval of the first coil; and

the step of removing the second plating underlying film on the insulating film of the first coil.

4. A thin film magnetic head comprising a thin film coil comprising at least a first coil and a second coil formed on a same substrate, two magnetic cores provided with the thin film coil held therebetween, and a magnetic gap held between the tip portions of the two magnetic cores;

wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film; and

the conductor of the second coil is formed on the substrate with the insulating film formed therebetween.

5. A thin film inductor comprising a thin film coil comprising at least a first coil and a second coil formed on a same substrate;

wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film;

the conductor of the second coil is formed on the substrate with the insulating film formed therebetween;

the first coil and the second coil of the thin film coil are electrically connected to each other; and

one end of the thin film coil is connected to the outside, the other end being a free end.

6. A thin film magnetic sensor comprising a thin film coil comprising at least a first coil and a second coil formed on a same substrate;

wherein at least the entire side surfaces of the conductor of the first coil are covered with an insulating film; and

the conductor of the second coil is formed on the substrate with the insulating film formed therebetween.

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